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A PRELIMINARY ENVIRONMENTAL
ASSESSMENT OF OFFSHORE DRILLING
FOR OIL IN THE BEAUFORT SEA

EVIDENCE OF

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INTRODUCTION

Drilling for oil using ice-strengthened drill ships is proposed for ice-free periods starting in the summer of 1976 at two sites. These sites, shown in Figure 1, are inaccessible during the winter and spring to any existing drilling systems. The scale of activities for 1976 is small, therefore the only really major impact on the environment would result from oil discharged into the sea in the event of an underwater blowout. Although the possibility of a blowout occurring is remote, it cannot be ignored. There is a whole series of possibilities and conditions that will determine the severity of the impact of a blowout on the environment such as:

- whether it is just a gas blowout;
- if it is gas and oil, what is the discharge rate of the oil;
- whether or not it is self-sealing;
- when during the drilling season the blowout occurs;
- how long it will run wild before a relief well could shut it off;
- what kind of oil it is;
- the probable effectiveness of proposed oilspill countermeasures;
- where the escaped oil would spread to;
- how weather conditions, such as storm surges, wind and sea state would affect the spread of oil and the ability to contain oil;
- once spread to coastal areas and in the sea ice, what its affect would be on organisms;
- would there be any changes in the climate;
- how long would it take for wildlife populations to recover;
- would there be local and possibly international ramifications to depletions of some wildlife species.

This report is an *environmental assessment* and by assuming hypothetical worst-case oil well blowout scenarios, examines the nature of the transport and fate of oil in the Beaufort Sea.

Assuming a "worst-case" sub-sea oil well blowout, major conclusions are as follows:

- the blowout would run wild for at least one year, until a relief well could bring it under control;
- access to either site for relief well drilling in any summer is not guaranteed;
- even though a wild well could discharge oil for a year or more into the Beaufort Sea's ice, any premature melting which would be caused would be indistinguishable from natural ice-cover fluctuations; hence, no climate changes should be attributed to oil in the volumes expected;
- oilspill countermeasures for 1976 will not greatly decrease the impact of oil on wildlife;
- the wildlife most seriously damaged would be seabirds;
- it is judged that none of the damage would be irreversible but that recovery would be as long as a decade in some cases;
- except for birds the economic values of Beaufort Sea wildlife are small compared to oil industry expenditures. The birds are a continental resource with a high indirect economic value. The major values threatened must be judged primarily on sociological and environmental grounds, not economic.

EXPLORATORY DRILLING, 1976

The Concern: Almost the whole of the Canadian portion of the continental shelf of the Beaufort Sea has been subject to permits by oil companies for a number of years. Seismic and other geophysical surveys have been carried out fairly intensively over the whole area. It is regarded as promising with respect to gas and oil reserves. To date the only drilling which has taken place offshore in the Beaufort Sea has been from artificial islands constructed in shallow water close to the Mackenzie Delta. However at least some sectors of the industry are now anxious to see exploratory drilling in areas of deeper water farther offshore.

The Canadian Marine Drilling Ltd. (Canmar), a subsidiary of Dome Petroleum, plans to drill two wildcat wells in the southern Beaufort Sea during the summer of 1976. Two drill ships, currently under modification in Galveston, Texas, expect to be simultaneously "spudding in" on two continental shelf sites by the 1st of August (Figure 1).

In the future, an expansion of exploratory drilling, perhaps followed by the drilling of production wells and the laying of pipeline networks will clearly have extensive environmental and sociological implications which will have to be dealt with by appropriate authorities. However, of immediate concern is how the Beaufort Sea environment might be degraded by Canmar's proposed exploratory drilling in 1976. The major immediate environmental threat connected with this limited exploratory drilling program is a marine oil well blowout.

Three questions arise: What is the probability of a blowout? What are the probable consequences of a blowout? What is the capability to control the blowout and to clean up oil which escapes control? This preliminary assessment is mainly concerned with consequences and clean-up, but it must also deal with the nature of ice conditions in the Beaufort Sea as it influences the viability of drill ships' operations, and in particular, their ability to drill a relief well.

To date drilling authorities in the Arctic and elsewhere offshore have been granted where it is possible to extend the drilling season sufficiently long in order to implement measures to control a wild well. However, such precedences cannot be strictly adhered to at the proposed drilling sites. It is evident from the description to follow that if a blowout were to occur in the latter part of the drilling season of 1976, the earliest completion date for a relief well would be toward the end of September, 1977, and there is no assurance that the well would not run wild for yet another year.

Canmar's Sites and Relief Well Drilling: Drill ship operations on the continental shelf of the Beaufort Sea differ significantly from those in areas explored hitherto. The major difference is the presence of sea ice which would preclude drilling operations from ships for the greater part of the year, and in some years for the whole year. For example, if Canmar had been granted a drilling authority for operating with two drill ships starting the summer of 1973, they could possibly have completed two wells in 1973, would have been able to conduct virtually no drilling in 1974 and could have started two, but at most completed only one, in 1975. If a blowout had occurred in late 1973, and had not been self-sealing, it would not have been possible to start a relief well in 1974. One could have been started in 1975, but it is not certain that it would have been possible to complete it.

Canmar has incorporated special ice resisting features in their drill ships and supply vessels in order to combat ice intrusions. The extent to which these features may be successful is touched on later.

The problem of drilling a relief well is aggravated by the fact that both of the Canmar sites are located within a transition zone between the offshore polar pack to the north, and what late in winter becomes landfast ice to the south. During winter the transition zone contains ice which is moving and actively shearing. Although ice breaking vessels could be used to extend the drilling season into the fall, the ice in this region can be too thick in winter to be handled by an existing ship, including the largest icebreakers, but at the same time it is too mobile to permit the use of ice as a platform from which to drill a relief well. Only in a summer period of perhaps three months, and sometimes not even then, is there a time interval in which drill ships can operate.

The probability of an oil or an oil and gas well blowout is judged to be in the range of 10^{-3} to 10^{-4} for each well drilled. As more wells are drilled, the cumulative probability of a blowout would increase. However, if experience is gained in drilling in the Beaufort Sea, the risks per well could be reduced.

Some Effects of Crude Oil on the Aquatic Ecosystem: The effects of the interaction of crude oil with marine organisms are complex and are extremely difficult to predict in advance of a polluting incident. Direct mortality of marine life through poisoning, coating and asphyxiation is usually associated with coastal oil spills. There is also physiological damage to organisms such as reduced fertility and lower body resistance to infection, generally resulting from prolonged exposures to sublethal levels of oil. Disruption of normal migratory and spawning behaviour and feeding habits can occur due to the animals' avoidance reactions to oil. Sometimes there is absorption of oil particles into suspended solids which eventually settle to the sea bottom. These sedimented oil particles could be chemically re-introduced into the food web by benthic feeders. Changes in water chemistry resulting from the introduction of water-soluble components of crude oil can upset the natural balance of dissolved gases and nutrients.

The extent and severity of damage to arctic marine organisms by crude oil depends on numerous factors such as the amount and type of crude oil spilled, the location of the spill, the time of year, the presence of sea ice, water turbidity, and obviously the abundance and distribution of plant and animal life and their exposure time to the oil.

Blowout Scenarios and the Effectiveness of Oil Countermeasures: Canmar has taken the question of countermeasures in the event of a blowout seriously. To what extent can their proposed countermeasures reduce the damage which is to be expected in the event of a blowout? A realistic examination of this question leads to the conclusion that although under very favourable conditions a large fraction of the oil released might be successfully dealt with, the percentage of the time of a blowout when these very favourable conditions would occur is an estimated 45% so that a large fraction of the oil would escape. Indeed since the rate of flow of oil used in a scenario is entirely hypothetical, (the actual flow could vary from a small fraction of a hypothetical 1500 barrels a day to several times this) it would seem necessary to assume in any blowout scenario that the oil which escapes is not much less than the oil released by a blowout. No control systems at present available, including the ones proposed



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by Canmar, (other than sealing off the well by the drilling of a relief well or some other technique), shows promise of reducing the possible damage from an oil spill by a factor of ten.

The Preliminary Environmental Assessment: The method adopted in this preliminary assessment is to compare the potential for damage which would result from an oil well blowout occurring at either of Canmar's sites #1, #2 and at a hypothetical site #3 located in the landfast ice zone. Pathways and fates of oil are described in scenarios, or narratives; these are used as the foundation for assessing the impacts on wildlife.

THE BEAUFORT SEA

Geographical Setting: The region of immediate concern is the southeastern Beaufort Sea which lies between the Alaska-Yukon border on the west to Cape Dalhousie in the east and northward to 72° N. Offshore permits, granted to oil companies, (Figure 1) extend 170 km seaward to depths of 1000 m, but generally do not reach beyond the upper continental shelf.

During the months of July, August and September there is often extensive open water navigable by ice-strengthened vessels to varying distances offshore depending on the distance the polar pack recedes northward.

Three main underwater physiographic features are present: the *continental shelf* which grades gently toward depths of 100 m; the *continental slope* which falls steeply from the shelf edge; and, the V-shaped *Mackenzie Canyon* which transects the continental shelf. Features on the continental shelf are ice-scour marks and pingos. Ice-scours are linear troughs produced mainly by the keels of pressure ridges in the winter and are evident in all depths to 75 m or so. Pingos, occurring sporadically on the shelf, are ice-cored conical mounds up to 300 m in diameter at their base and rise within 15 m of the sea surface. Another feature of the shelf is the existence of sub-seabottom permafrost. While drilling through sub-sea permafrost is more related to drilling technology than ecology, it is a factor which makes offshore drilling in the Beaufort Sea different from other areas. Discontinuous permafrost is generally less stable than continuous permafrost because it is closer to the melting point.

The coast is generally low-lying; the Yukon coast, west of the Mackenzie River, differs from the outer coast of Richards Island and Tuktoyaktuk Peninsula. The Yukon coast is characterized by three main features: steep coastal cliffs containing ground ice and fronted by narrow beaches; spits and barrier beaches up to 10 km long and a few hundred meters wide; and partially vegetated deltas of coastal rivers, such as the Babbage and the Blow. In contrast, the north shorelines of Richards Island and Tuktoyaktuk Peninsula have deep embayments caused by the breaching of thermokarst lakes which are particularly common on the Mackenzie River delta. Sediments from coastal retreat move locally up and down the coast.

Sea Ice Features: The growth, movement and decay of the sea ice in the eastern Beaufort Sea is influenced by the polar pack interacting with the coastlines, the Mackenzie River and the arctic climate. The average movement of the offshore pack ice is caused by mean wind stresses over the Arctic Basin, resulting in a clockwise gyre or ringlike movement. The clockwise speed of the ice near the rim of the gyre varies from zero at times, to as much as 25 km/day for short periods in the springtime. Its average yearly speed is about 3 km/day.

In summer, the polar pack consists mainly of multi-year floe ice, pressure ridges, rotted 1st year ice, leads and large pools. In the winter, growing 1st year ice replaces the open water and the wind-stresses on the ice produce flaw-leads and new pressure ridges. Under short-term wind stresses, the centre of the gyre can shift, resulting in onshore or offshore movements. Onshore movements in the winter and spring are limited by the growth of landfast ice in the coastal bays and shallow shelf waters; the landfast ice generally extends seaward to depths of 25 m. In the summer however, excursions of polar pack ice into the southeastern Beaufort Sea are controlled by the vast flow of fresh water from the Mackenzie River, local wind fields and the shallow shelf waters.

Extensive scours are produced on the sea-bottom of the shelf by the onshore and alongshore movements of sea ice. These are produced mostly in the winter and spring by the grounding of under-ice projections such as pressure ridge keels. Scour trenches generally do not exceed 2 m in depth, but in places are as much as 6 m deep. Scouring is common in water depths of 15 m to 45 m with the maximum activity at 30 m within the transition zone.

During November and December, the landfast ice grows in thickness and increases its area in a series of steps seaward depending partly on onshore winds. These winds consolidate loose floes at the fast ice edge where they remain in place during offshore drifts. By April, the landfast ice has grown to a thickness of 2 m.

Although the polar pack is sometimes blown well offshore in a light ice year, its nearshore boundary in winter usually lies over the 500 m depth contour near the edge of the continental shelf. Lying between this pack edge and the fast ice is a *transition zone* of deforming, sporadically moving, heavily ridged and highly irregular ice. This zone of active shearing provides open water, albeit temporary and variable, in winter and spring. The transition zone ice often resembles the polar pack but includes an increasing number of pressure ridges and more first-year ice as the landfast ice is neared.

The beginning of break-up in the southern Beaufort Sea is first evident as early as March with the widening of flaw-leads west of Banks Island, under the thrust of E and SE winds. The simultaneous westward and clockwise movement of the gyre away from Amundsen Gulf produces another long flaw-lead at either the seaward edge of the landfast ice or further offshore in the transition zone. Additional radial leads, perpendicular to the coast, also open in the transition zone, forming part of an extensive interconnecting lead system. By April, ice from Amundsen Gulf moves westward to fill the increasing spaces of open water between the fractured ice of the transition zone. Figures 2 to 6 show major ice movements observed in NOAA satellite imagery from March 11 to June 21, 1975.

By mid-May, the Mackenzie River is in freshet and one month later, considerable open water exists in the nearshore waters of the Mackenzie and Kugmallit Bays. By early July the coastal fast ice has disintegrated and moved offshore with the polar pack. If, however, westerly winds prevail throughout most of the summer there will be a heavy ice year such as in 1974 when the ice boundary was roughly on a line between Herschel Island and Atkinson Point on Tuktoyaktuk Peninsula. Generally the summer and fall pack ice edges are distorted southward with protruding tongues and eddies of floe ice. It is likely that the floe tongues will cause extensive interruptions to drill ship operations at the Canmar sites. The main characteristic of the ice in the southeastern Beaufort Sea is the extreme variability of its extent and movement which render terms such as "average ice concentrations" and "average ice year" of little use.

Oceanographic Features: In the southeastern Beaufort Sea the Mackenzie River outflow meets and mixes with the salt water of the Arctic Ocean over much of the wide continental shelf. The Mackenzie River is in freshet from mid-May to early August. During the late winter and spring the flow is reduced to 1/10th of this rate as it spreads out under the landfast ice. The plume of fresh, muddy water flows out over the more saline ocean waters, but when the Beaufort Sea is covered with ice or in the absence of winds, will turn eastward along the shore of Richards Island and Tuktoyaktuk Peninsula toward Amundsen Gulf.

The turbid fresh water layer from the river is normally from 2 to 5 m in thickness, however this thickness increased to 8 m or so in the heavy ice year of 1974, as a result of the damming effect of the polar pack pressing close to shore. The fresh water layer on the surface and those beneath can have quite different currents, both in direction and speed. When offshore winds drive surface waters north, deeper oceanic waters must replace them in an underflow. Conversely, the fresh surface layer thickness with onshore winds with a resulting expulsion of saline waters offshore. These counter-currents can cause deep-draught floes and thin brash ice to move in opposing directions.

An important consequence of the river flow in the winter and spring is that the shallow inshore waters are brackish east of Richards Island and along Tuktoyaktuk Peninsula. Hence there is over-wintering habitat in the shallow lagoons, estuaries and breached thermokarst lakes well suited to non-oceanic species of fishes, invertebrates and micro-organisms.

Another feature of the river is its high mud load, hence low light penetration which inhibits primary biological production except where river borne nutrients can be utilized outside the turbid plume.

Storm surges (wind tides) occur frequently in the southeastern Beaufort Sea. These are increases and decreases in sea level other than tidal, caused by a wind-driven pile-up of water on the continental shelf. At Tuktoyaktuk, between 1962 and 1973, 22 positive and 5 negative surges (offshore winds) were recorded. Two were more than 2 m above normal tidal fluctuations of 0.3 m. Ten occurred during the light ice year of 1963. The offshore condition necessary for a storm surge is a fetch of 50 km or so of open water containing ice in concentrations of 3/10 or less with minor floes. Surges are normally accompanied by large wind-waves, rapid coastal erosion and inundation of coastal lowlands. Driftwood strand lines, 2 m or more above sea level, show that the coastline from Herschel Island to Cape Bathurst has been subjected to storm surges. A winter surge of 1 m was recorded on January 6, 1974,

generated by the passage of an intense low pressure weather system through the northern Beaufort Sea. The ice slackened toward the north with offshore winds, then closed with strong inshore winds. After the wind shift, the ice concentration was low enough to generate water movements toward the shore. Although this surge was not in itself a damaging event, winter surges could cause unusual displacements in the landfast ice and complicate the prediction of oil transport in the event of a blowout.

In summary, large positive storm surges require extensive open water and are caused by strong W or NW winds. Open water is also desired for offshore drilling using ships. High winds are more likely in September and October (the 2 m surges at Tuktoyaktuk occurred on 4 September, 1962 and 4 October, 1963). Oil from a blowout near the end of the drilling season could co-exist with a storm surge to transport oil inshore onto the lowlands.

Wildlife in the Southeastern Beaufort Sea: Compared to adjacent Bering and Chukchi Seas, the Beaufort Sea has been described as a "cold, biological desert characterized by nutrient-poor waters, year-round presence of ice and long winter darkness". Although this description was specifically written in context with the growth of arctic marine primary organisms, the phytoplankton, this general concept is commonly, but mistakenly, applied to all trophic levels of plants and animals and to all seasons of the arctic year.

This region falls under the influence of pronounced seasonal changes in temperature, sunlight, precipitation, run-off, sea ice and snow cover. Winter production of phytoplankton, the basic food supporting all higher animals is nearly zero in the dark waters beneath snow-covered sea ice.

The period of high primary productivity is consequently short and the total yearly production is low.

The biological nature of the southeastern Beaufort Sea is highly dependent upon the balance between the Mackenzie River outflow and offshore marine waters. The bleak nearshore plant production results from insufficient light penetrating the muddy water even though there are plentiful river-contributed nutrients. Consequently the zooplankton primary consumers, consisting mostly of crustaceans, especially copepods, are found in low numbers within the Mackenzie River plume but increase in numbers further offshore. The low-salinity coastal waters along Tuktoyaktuk Peninsula comprise the summer, as well as the winter habitat of many anadromous and freshwater fish, predominantly of the whitefish family. The deeper bays and lagoons such as Liverpool Bay, Mason Bay and Tuktoyaktuk harbour are sites of high primary production. In coastal embayments there are more bottom organisms than on the shallow continental shelf. The richest waters are offshore at depths between 30 and 100 m, particularly north of Baillie Islands.

Many of the fish species found in northern Canada occur in the Beaufort Sea. In the western Arctic where the Mackenzie River is a major influence, large numbers of anadromous fish move into the Beaufort Sea to feed on marine animals. Most of these migrations are confined within relatively low-saline coastal waters. Tuktoyaktuk, Mason and Mallik Bays or any of the numerous bays and lagoons with sea access serve as nurseries for large numbers of young fish in summer and winter.

Important animals are ringed and bearded seals. The ringed seal feeds on

many points of the arctic food web and is not restricted geographically by its food supply. In contrast the bearded seal is limited to an effective feeding depth of 90 to 100 m. It feeds almost entirely on large burrowing or sedentary bottom invertebrates of shallow continental shelf waters. Although this seal is as well adapted as the ringed seal in keeping air holes open in thick landfast ice, it does not choose to do so. In winter, bearded seals, young and old alike, are often found concentrated along the edges of leads in the transition zone ice.

Other than seals, year-round residents are the polar bear and arctic fox, both predators of the ringed seal. The arctic fox spends a large part of its life on the sea ice, often hundreds of kilometers offshore in seas bordering western Banks and Victoria Islands.

Sea ice habitat supporting seals is also the habitat of the polar bear. When possible, polar bears remain with the ice because of the accessibility of seals. In winter and early spring, bears tend to concentrate in the transition zone ice, where ice movements form leads and open water. A small part of the Beaufort Sea population is shared between Canada and Alaska. This fact, in part, prompted the 1973 International Agreement on the Conservation of Polar Bears between Canada, the United States and other nations.

The arctic spring is heralded by the arrival of migrant wildlife which expect to capitalize on long hours of sunlight, relatively few predators, and the seasonal abundance of food necessary for their successful propagation. Bowhead and beluga whales are almost the first arrivals, travelling from the north Pacific eastward into the Beaufort Sea. Their migration occurs in May or June through the network of leads and open water north of the landfast ice. Both species pass by the Mackenzie Delta, exploiting the flaw leads between the landfast ice and the polar pack.

Beginning in May, several millions of birds converge to nest in the western Arctic from wintering grounds representing one-third of the globe. Most bird species are aquatic, migratory and important locally for native subsistence or for the recreation of North American hunters and birdwatchers. Of the approximately 100 species nesting around the rim of the Beaufort Sea and the Arctic Islands, approximately two-thirds migrate through the Great Plains, Mackenzie Valley or northern Great Lakes, while the other third pass the Bering Straits and follow the coasts of Alaska, Yukon and Northwest Territories. Along this coastal route, some geographic and biological features tend to concentrate birds when migrating, feeding, nesting or moulting. For spring migrants the patches of open water, ice leads and melt ponds of the transition zone ice are most important for resting and feeding. The leads of shallower water depth are particularly popular stop-overs where the diving birds such as loons, oldsquaws and eiders can easily feed on the bottom marine organisms. One of the more permanent open water areas is the polynya north of Baillie Islands. The barrier beaches, and sand bars extending from Tuktoyaktuk Peninsula and Mackenzie Delta west to Herschel Island, and along the Alaska coast to Point Barrow are important nesting grounds wherever they form islands inaccessible to predatory animals such as fox. Eiders, oldsquaws, gulls and terns are usually found nesting in such places. The sheltered lagoons behind barrier beaches and sand bars serve as rearing and moulting places for seabirds, as well as habitats for fish and other marine fauna upon which seabirds feed. The deltas and tide flats of the Mackenzie and other nearby rivers are also major Canadian nesting grounds for ducks, geese and swans.

SCENARIOS FOR OIL AND GAS WELL BLOWOUTS IN THE BEAUFORT SEA

Exploratory Drilling in the Summer of 1976: The present plans of Canadian Marine Drilling Ltd. (Canmar) are to send their two drill ships into the southeastern Beaufort Sea as early as possible in the summer of 1976. Assuming that 1976 will be a year of light ice, the earliest date that the ships may begin drilling is about the 1st of August. If it is a heavy ice year, it is unlikely that the ships could proceed to their drilling sites at all.

The two drilling sites proposed for the summer of 1976 are shown in Figure 1. Site #1 is in a water depth of 26 m and located about 46 km seaward of Tuktoyaktuk Peninsula; Site #2 is in a depth of 58 m at a distance 83 km offshore of Pelly Island. Both sites are situated in the transition zone ice. The drilling season is not likely to extend beyond mid-October, allowing only 2 1/2 months at either site to drill down to possible petroleum-bearing strata. The likelihood of a blowout of oil is increased toward the end of the drilling season as petroleum is encountered.

Assuming the postulated blowout occurs on the 5th of October, the second drill ship could, at most, begin work on drilling a relief well but would be unable to drill down to the petroleum-bearing horizon to control the wild well before freeze-up. In this event we would be faced with a free-running blowout and little hope of controlling it until at least 10 months later, in the following summer. Even then it would depend on having a favourable ice year to bring it under control.

In some geological oil-bearing structures, debris entrained in the gas and oil within the well-bore can gradually quench or reduce the flow of a wild well. However in the worst case the well could free-run throughout the fall, winter and spring, until the summer of 1977 when action could resume to drill a relief well to bring the blowout under control by that season's end.

The Underwater Oil and Gas Well Blowout: What would this blowout be like? It is postulated that the initial flow of crude oil could be 2500 barrels/day and that this flow could decline to 1500 barrels/day in one month's time as the local region of the reservoir is drained. 1500 barrels/day equals 240 cubic meters of oil per day or 87,600 cubic meters/year assuming the well does not self-seal. About 1.2 million cubic feet (34,500 m³) of gas/day are also likely to accompany the crude at the sea surface.

Since the blowout orifice is at the sea bottom, the gas rises to the water surface in bubbles, carrying the oil with it, in effect creating a bubbler system which circulates bottom water toward the surface. At the well-head orifice on the bottom the oil is churned into droplets which rise toward the surface at varying rates. Some of them will coalesce to form larger drops; others, being very small, will remain suspended in the water column for some time and therefore will be moved at the whim of the sub-surface ocean currents. A contingency decision may be made at this point to fire the blowout if it is not already on fire. Assuming calm waters, little ice and negligible currents, it is possible that 90% of the oil could be burned off, although this has not been demonstrated. The tarry residue would be retained locally by the natural water-circulation generated by the rising bubble stream. This simplification breaks down when we consider ocean currents, surface waves and moving ice floes. The following paragraphs will describe the possible transport and eventual fate of oil following such a blowout.

Transport of Oil During the Fall and Winter: The two proposed drilling sites are strongly influenced by the Mackenzie River. When offshore winds blow, the fresh water of the river moves over the more saline, cooler sub-surface waters. This surface layer of river water is muddy and can be up to 8 m thick. Often the currents in these thin surface waters are quite different from those beneath the sub-surface more saline water. The surface waters are driven mainly by the wind, while the sub-surface waters are moved by oceanic influences. To complicate flow predictions, young ice or thin rotten floes, which draw little water, commonly move in the direction of the surface currents while deep-draft old floes travel against this surface current, under the influence of sub-surface currents. Often, there will be no simple puddle of oil to burn. If a large ice floe happened to float over the site of a burning blowout, the fire is likely to be extinguished.

Violent storms are common in the fall of the year. In October, offshore winds drive the newly-forming ice away from the shore and out to sea. Strong NW winds follow in November, whipping up the waves and driving the ice back to the coast. It is not likely during the late fall that an ignited blowout will remain on fire. The oil will be blown by the wind, be emulsified to some extent and eventually be driven toward the shoreline of Tuktoyaktuk Peninsula. Here, the Mackenzie River flow will transport the oil along the shore of the peninsula to the northeast. Modest, 1 m storm surges occur in mid-October under the thrust of onshore winds so that the innermost reaches of breached thermokarst lakes, bays and lagoons could be contaminated by oil. As the sea calms between storms and the landfast ice begins to form from new grey ice and floe fragments, some of the oil will remain mixed-in with the surface of the landfast ice. The most rapid reduction of the flow of the Mackenzie River occurs in November and by mid-month the flow is 15% of the mid-summer flow (Figure 10). At this time, the ice forming on the continental shelf can move westward as the offshore influence of the NE river flow diminishes.

Marine inshore and offshore oil clean-up equipment, consisting of floating booms, devices to separate oil from water and floating incinerators, will be completely inoperable much beyond freeze-up in October. Canmar may attempt to re-ignite the blowout by dropping incendiary material from aircraft at the site. These efforts could be frustrated by intruding ice floes which frequently snuff out the flames. There will be discontinuous movements of multi-year pack ice over the site, remnants of the past season's first-year ice and new ice. Leads in this ice can form, freeze and be compressed, the new ice being crushed and mixed with oil.

Storm surges sometimes occur during the winter in the southeastern Beaufort Sea. These would not necessarily result in oil reaching the frozen shoreline but could produce a rim of oil along the coastal landfast ice. Since a winter surge can cause a 1 m rise in sea level at Tuktoyaktuk, oil would contaminate any ice-free shores but would not enter ice-covered bays and lagoons.

By late January, the landfast ice has formed, though incompletely, to seaward and the ice in the transition zone is moving irregularly westward. Within the transition zone there is often a wide lead or network of leads and cracks caused by the offshore retreat of the arctic pack when S or SE winds blow. It is estimated from satellite imagery (Figures 2 to 6), that Canmar's Site #1 will be in open water or water covered with new grey ice an estimated 50%

In summary, assuming a blowout occurred on October 5, 1976, at Canmar Site #1, the oil could be dispersed in early May as shown in Figure 7. Assumptions are that: 3,500 m³ will be blown toward the coast by winds associated with a storm surge on October 10; 5,000 m³ will have been dispersed NE towards Banks Island in the fall; 22,000 m³ will be dispersed in the growing and seaward extending landfast ice, part toward the NE until mid-November and the remainder to the west until late January; finally 23,000 m³ will be distributed along the north edge of the landfast ice 400 km to the west or 75 km west of the Alaska-Yukon border as far as Barter Island.

A blowout at Canmar Site #2 on the 5th of October, 1976 would likely produce a somewhat different distribution of crude oil by May 5th, 1977, as shown in Figure 8. Site #2 would seldom be in open water in the late winter so that from late January to early May the oil would be mostly encapsulated within the ice of the transition zone. Prior to this, much of the oil would be incorporated in the landfast ice as depicted for Site #1, although somewhat less since the westward ice circulation would be established sooner offshore.

For comparison with the two Canmar sites, a hypothetical landfast Site #3, at a depth of 18 m is shown in Figure 9. The only significant difference in the distribution of the crude oil from an October 5th blowout at Site #3 would be the containment of the oil within a restricted area in the landfast ice by late January. If all the oil from late January until break-up of the landfast ice is eventually burnt, the disposition of the oil could be as depicted in Figure 9 on the 5th of May, 1977.

In Figure 7, the oil contaminated landfast ice covers an area of approximately 7,700 km². Most of the 22,000 m³ of oil in the landfast ice would likely be concentrated in narrow bands or ridges parallel to the coastline. A useful visualization is that the oil coverage would be equivalent to forty bands of oil 0.3 cm thick and 1 m wide, each spaced 1 km apart. In the area south of Banks Island, shown contaminated by 5,000 m³ of oil, the average oil concentration would be one-half the amount computed for the landfast ice. These concentrations also apply to the oil dispersals shown in Figures 8 and 9.

Any consideration of weathering which would apply to a large fraction of the total oil discharged from a blowout at Site #1, and which could reduce the oil volume by 30% has been ignored. Weathered oil would be difficult to burn. In contrast, oil trapped in the ice remains in its original state. That oil droplets rising from the sea bottom well-head have different residence times in the water column and can be dispersed widely depending on the subsurface currents, is also ignored. Therefore one might expect to have a considerable number of droplets, perhaps 2% of the total oil volume, incorporated into the ice sheet well beyond the estimated swath widths. It must be emphasized that the swaths of oil under the transition zone ice would not be continuous ribbons of oil but would often consist of disjointed segments. It is likely that the detection in the spring, of the fragmented oil trails originating from Site #2 in particular could be aided by radio beacons deployed near the blowout site at intervals throughout the winter.

Seasonal Effects on Oil in Ice during May, 1977: Early May is a critical time in the Beaufort Sea. The sea ice ceases growing; the brine in the ice would be replaced by oil which will slowly rise to the surface of the ice.

The sun's heat, absorbed by the dark-colored oil within the ice, will create melt pools which form natural containers for the surfacing oil. At the same time, the offshore leads form a network of highways and feeding locations for migratory and resident wildlife. Much of the oil locked into the ice throughout the winter and spring resulting from a blowout at Site #1, would be released precisely in the main migration routes.

Early May is also the optimum time to initiate disposal of oil by burning. The oil which has been trapped within the ice in a fresh state will burn easily as it emerges; however, the weathered oil at the surface will not burn readily. Judging from the scenarios of oil dispersal, 60% of the oil from Site #1 could be weathered and about 40% from Site #2. The unweathered portion would emerge from within the ice as small scattered patches and pools along paths extending 400 km to the west. Burning significant fractions of this oil, perhaps at most 20%, is questionable in view of the vast areas to clean up, the short two weeks or so of time available before the oil surfacing would become too weathered to burn, and the poor flying weather existing toward mid-May.

Oil Movement in June to early July, 1977: In June, the ice is rotting rapidly and constantly moving at the whim of the wind. Gradually, in early July, the landfast ice breaks up and moves offshore. Larger floes break up into smaller floes. With air support, maintenance of a conflagration at a blowout site would become easier since the floes will be rotten and more permeable to gases. By early July the Canmar tugs and oil clean-up equipment could attempt to proceed to the blowout site to corral the oil. However, in heavy ice years, migrations of floes near Site #1 and more so at Site #2, would frequently frustrate the effectiveness of oil clean-up activities. At hypothetical Site #3 (Figure 9), oil containment and burn-off would be interrupted briefly as the landfast ice breaks up and moves offshore allowing marine equipment to approach the blowout site.

In spring 1977, the Mackenzie River will be at its maximum flow. The surface waters, in calm weather, will carry the landfast ice offshore and to the northeast while prevailing winds will tend to move the pack ice to the northwest. A likely result will be that prior to early July, this interaction of winds and currents will move the oil fixed in the landfast and transition zone ice into the arctic pack. There the oil will weather and merge with rotting floes and reside within the open pools and leads at the southern periphery of the gyre. Consequently most Canadian shoreline contamination other than that from mid-October, 1976, could be caused by oil escaping containment and clean-up from early July to the end of summer. Much of the oil discharged earlier will have travelled westward with the pack ice to north of the Alaska coast as far as Point Barrow.

Climatic Effects: The amount of weathered oil which would be dispersed from a single oil well blowout running wild for a year would be unlikely to have any effect whatever on global or even local climate. While it is certain that oiled ice will melt much faster than clean ice, natural fluctuations in the yearly ice cover would mask the extremely small changes which would be caused by oil in the volumes assumed.

Relief Well Drilling in the Summer of 1977: In the meantime, plans for relief well drilling will be laid by Canmar. Following news of a blowout in October, two of Canada's largest icebreakers may be overwintered in the southeastern Beaufort Sea to assist a Canmar drill ship to maximize its 1977 drilling season. Plans will have been set for burning the oil expected to emerge from the sea ice in early May. Also, supplementary offshore and inshore booms, skimmers and burners will be mobilized in the delta. Ice-strengthened tugs and aircraft support will be prepared for the anticipated oil countermeasures operation in the summer. Steps will be taken to set up a comprehensive environmental prediction system to support marine operations and to predict oil-slick movements.

Drilling a relief well to control a blowout is a more complex operation than either wildcat or delineation drilling. Despite better knowledge of geological formations, it cannot be expected that less time will be taken to drill the oil reservoir than it did to drill the original well. The scenario assumed 60 days of drilling in 1976 before the hypothetical blowout occurred. Spudding-in for a relief well at either Canmar site could occur on July 15, 1977. Assuming there were no significant interruptions, control could be gained by October 1, 1977. From July to October 1, the blowout could have discharged 21,000 m³ of oil and 3.1×10^6 m³ of gas at the sea surface.

As with the original well, the blowout preventor (BOP) stack of the relief well will be placed in a jetted-out cavity or in a silo in the sea bottom to protect it from intruding polar floes in the summer. Figures 10, 11 and 12 show tracings from satellite imagery of ice floe intrusions in the vicinity of the Canmar sites in late August of the years 1973, 1974 and 1975. Few clear images of the Beaufort Sea are available in the summer because of cloud cover. However on the dates shown, serious delays would have occurred at Site #1, in all three years while Site #2, visible only in Figures 15 and 16, was covered by large floes. The circles scribed around Site #2 depict Canmar's 24 hr, 12 hr and 4 hr alert zones (ranges 18, 10 and 5 nm) for winds ranging between 10 to 20 kts. At Site #1, but more often at Site #2, large icebreakers would have found difficulty providing protection to a drill ship attempting to maintain its position. Hence, in heavy ice years, such as 1974, a relief well could not have been drilled using a drill ship. In contrast, during light ice years such as 1970 and 1971 (although only aircraft reconnaissance exists to confirm this speculation) the drilling season at both sites could have been a clear 120 days.

Estimates of Oil Escapement During the Summer of 1977: In addition to the weathered residue of the 3,500 m³ of oil reaching the shores in mid-October of 1976, the next oil to reach the coast could be expected from oil escaping containment from early July to early October, 1977. This assumes the relief well is successful in 1977. Except for periodic intrusions of pack ice from the north over the blowout, it is also assumed that the southeastern Beaufort Sea will be ice-free in 1977, therefore the movements of the free oil will be governed by the winds and local surface currents. In the absence of winds, the surface currents have minor tidal components but are mostly from turbid fresh river water extending to beyond the Canmar sites and trending to the northwest to Amundsen Gulf. Onshore and offshore winds modify this flow as outlined earlier. It is clear that west and northwest winds will drive floating oil to the sea coast along the shores of Richards

Island and Tuktoyaktuk Peninsula. If coincident with these winds there is a large expanse of open water, a storm surge will be generated. Minor surges of 1.0 to 1.5 are common throughout the summer; for example, in 1963 between July 5 and October 16 there were ten surges. One exceeded 2 m and seven had amplitudes in excess of 1 m. Most years experience three or more surges in the summer.

Weather systems move through at approximately 2-week intervals in the summer resulting in an equal probability of northwest and southeast winds, therefore the 21,000 m³ of oil, if not burnt or contained, will fan out in all directions to the boundaries and edges of the ice-free waters of the southeastern Beaufort Sea, with a slight bias to the northeast due to the river flow. Assuming a paraffinic crude oil, 30% of this volume, or the more toxic light ends or aromatics, could evaporate within 48 hours. Of the remaining 14,700 m³, 50% or 7,350 m³ could impinge directly on the shorelines of Richards Island and Tuktoyaktuk Peninsula. The greatest concentrations would paint the exposed coasts, lowlands and inlets between Kugmallit Bay and Baillie Islands.

Oilspill countermeasures can reduce this quantity substantially, although their effectiveness both offshore and along the shore will depend almost entirely on periods of relative calm. The oil and gas blowout envisaged is unlikely to remain ignited in winds and waves since the wide-spread oil film could remain below its flash point. Winds, waves and accompanying surface currents would also reduce the effectiveness of containment booms. For the months of July, August and September of the years 1953 to 1972, offshore winds with speeds less than 11 kts (5.7 m/sec) were recorded about 45% of the time, hence a rough estimate of oil escapement from the blowout site is 55%. Inshore, the countermeasures' effectiveness could be poorer. In selected bays where efforts could be concentrated, 55% escape is likely. Using percentages of 55% offshore and 95% inshore, 7,350 m³ of weathered crude originally destined to reach the shoreline during the summer windy period would be reduced to 3,800 m³, flowing to the shore at a rate of 1,300 m³ per month.

This volume of oil could be added to the weathered residue of the 3,500 m³ of oil already on the coast from the fall of 1976. Assuming that weathering will leave 70%, the fall contribution will have been 2,450 m³ of oil. Taking into consideration the 400 km of coastline between Kugmallit Bay and Baillie Islands most likely to be affected, the 2,450 m³ from October, 1976 will paint the coasts with an amount of oil equivalent to a band 1 m wide by 0.6 cm thick. Then the 1,300 m³ per month could continue to increase the thickness of this band at the rate of 0.4 cm per month during the summer of 1977. It is probable that half of this oil would be immobilized on spits, bars and headlands, leaving the remaining half to contaminate estuaries, lagoons and low-lying coastal plains. During storms, oil can be incorporated into the sediments of bars and spits and can later be re-exposed to float on the water as these sediments erode some indeterminate time later.

Blowout Site Environmental Threat Comparisons: The fate of oil from both Canmar sites and hypothetical Site #3 has been described under the assumption that a blowout occurred on October 5, 1976. There would appear to be significant differences amongst sites regarding potentially damaging effects on marine wildlife. Referring to Figures 7, 8 and 9, and to the foregoing

description of summer conditions it is evident that:

- Oil blowouts at any of the three sites could be equally damaging to the coastal environment along Tuktoyaktuk Peninsula;
- Oil from hypothetical Site #3, in the landfast ice zone, would be least damaging to offshore migratory and resident wildlife, assuming that the oil can be burnt off or otherwise disposed of in a polynya in the fast ice during springtime;
- Oil from Site #1 would be most damaging to offshore migratory and resident wildlife because of its proximity to the main east-west lead immediately offshore of the fast ice. A large fraction, perhaps 60%, of the 23,000 m³ of crude oil discharged from late January to May 5 could be remobilized in this lead;
- Oil from Site #2 would appear to be less damaging than from Site #1 to offshore wildlife since much of the oil discharged offshore in the transition zone ice would be more widely dispersed and less available to contaminate the main east-west flaw lead used by resident and migratory marine mammals.

EFFECTS OF OIL ON BIOTA

In the following impact assessment the effects of oil on seasonal and resident biota of the southeastern Beaufort Sea are considered. Short-term and chronic responses to oil contaminated habitats at different seasons of the year are predicted. Emphasis is on critical niches and life patterns, such as migrations in leads, and overwintering in coastal bays.

Autumn (September and October): The imaginary blowout on October 5, 1976 at either Canmar site would deposit several thousand cubic meters of weathered oil on the northwest shoreline of Tuktoyaktuk Peninsula, in Kugmallit Bay and along the northeast coast of Richards Island. Compared to predicted quantities discharged offshore in the landfast ice and transition zone the coastal spill would be relatively small; nevertheless it would produce significant contamination of about 400 km of shoreline and embayments. A reduced impact of this pollution on the marine mammals and birds is predicted in autumn. Most seabirds, geese and shorebirds have migrated out of the Mackenzie Delta area by late September and October. Ringed and bearded seals are present but not concentrated, and could probably avoid slicks or contaminated inshore waters. The arctic fox is confined to the coastal tundra until the landfast ice forms. The intertidal zone of the Beaufort Sea is virtually barren and damage to invertebrate fauna would be minimal. During October or November, depending on when freeze-up occurs, the bears immediately migrate south, thus reaching more seals. Eighty-six percent of bear tracks observed in October are headed south. Many bears move out onto young sea ice barely thick enough to support them. In years when large amounts of pack ice are blown south to the mainland coast, such as in 1970 and 1975, bears are more abundant nearshore. It is not known whether or not polar bears actively avoid oil contamination. However, it is predicted that tens of bears could be in contact with oil, especially in the landfast ice zone and near the blowout site. However, the major ecological concerns in

coastal waters are the freshwater and marine fishes which, during October and on through winter, feed or migrate along the shallow inshore waters of Richards Island and Tuktoyaktuk Peninsula. Overwintering concentrations exist in Mason and Mallik Bays on Richards Islands, Tuktoyaktuk Harbour and in the numerous interconnecting embayments of Tuktoyaktuk Peninsula. An estimate of the standing crop for Mackenzie region freshwater and anadromous fishes is over 500 tonnes.

The same protected waters are nurseries or rearing habitat for fry which are swept down the Mackenzie River soon after hatching. Fisheries surveys have revealed that over 60% of the total fry catch from the lakes, streams, channels, and coastal waters of the Mackenzie Delta region are concentrated in low-salinity, shallow inshore waters. Here also are found several species of normally marine fishes such as herring, four-horned sculpin and arctic flounder, which are able to tolerate low-salinity waters. These move inshore as large schools by early summer to spawn in the shallow coastal waters of Tuktoyaktuk Peninsula. By autumn large numbers of herring fry are still inshore and could be subject to oil contamination.

Coastal bays and lagoons behind barrier beaches are natural traps for oil floating to the shore. Features of these habitats are frequent fall storm surges and between times, low rates of water exchange; both increase the chance of oil persisting in these highly productive fish habitats.

The significance of heavy fish kills of both breeding and juvenile components of arctic freshwater and marine stocks may be high. Undoubtedly the recovery of the populations to pre-spill status will be slow. Growth of the fishes is slow over a life span of 15 to 20 years. Maturity is usually delayed until age 5 years or older. Only once in every 5 or more years are successful year classes produced by many species. Repopulation in local areas of fish depletions is possible by immigration of unaffected fish from unpolluted areas of the Mackenzie drainage and nearshore waters. This assumes the fishes' food supply, mainly benthic invertebrates have recovered from oil pollution of the embayments. If considerable quantities of oil are buried in the bottom sediments, thus acting as persistence toxicants to bottom dwelling organisms, recuperation of fish stocks could be delayed for at least a decade.

Winter (November to April): Up to 15,000 ringed seals and 2,500 bearded seals are concentrated in leads of the transition zone from Herschel Island along the mainland and north to the west coast of Banks Island. Of these numbers, 35% of the ringed seals and 50% of the bearded seals are distributed along the active E-W shear leads between Herschel Island and Cape Bathurst which could be contaminated by tens of thousands of cubic meters of oil in the event of an oil well blowout at either Canmar site, but more so from Site #1. It is highly likely that these mobile animals will be in contact with oil to varying degrees.

Whether or not large seal kills will result from an oil blowout will depend on the duration of the seals' exposure to oil and their general state of health. Both species travel the network of leads in attempts to remain in ice free ones, thus minimizing the maintenance of breathing holes. As a result the probability of oil contact is high. The time of exposure to oil may, however, be short, depending on choices of escape routes. Experimentally, oiling of ringed seals has demonstrated that healthy animals are not permanently damaged by short periods of physical contact with Norman Wells crude oil.

Bearded seals feed mainly on zoobenthos such as gastropods, sea cucumbers and large crustaceans, hence oil contamination of the ice or water surface will not deplete their food supply.

In winter, ringed seals feed almost exclusively on arctic cod, the most abundant offshore fish which inhabits the under-ice surface and surface waters of the leads. Extensive oil contamination of the lead network will directly or indirectly degrade the local cod population by smothering under-ice algae and crustaceans upon which they prey.

Lack of food, lack of snow cover for birth lair construction, and heavy winter ice in the transition zone cause large natural fluctuations in productivity, nutritional states and population sizes of ringed seals. These, in turn, reflect on the distribution and survival of their major predators, the polar bears. For example, there was almost a 50% decline in numbers of ringed and bearded seals as well as a 10-fold reduction in the pupping success, both attributable to the heavy ice year of 1974. This resulted in redistribution of polar bears and poor survival of cubs. Environmental stresses will compound the debilitating effects of oil pollution; laboratory experiments show that ringed seals stressed by transportation and handling succumb within a few hours of exposure to oil pollution levels which are relatively harmless to unstressed animals. Natural wildlife mortality as opposed to that attributed to exploratory drilling activities will be difficult, if not impossible to determine. However, it is critically important to ensure that detrimental effects of exploration do not coincide with, and thus aggravate, stresses that seal and other wildlife populations may already be experiencing through natural causes.

If oil-related seal kills did take place north of Richards Island and Tuktoyaktuk Peninsula, the recovery of bearded seal populations would be slow. Since offshore leads are used for feeding as well as for breeding by this species, substantial numbers of breeding adults, adolescents and pups would be killed simultaneously. In contrast, the ringed seals' prime pupping habitat is the stable landfast ice to the east of the Mackenzie Delta and beyond potential winter contamination from a free running oil well blowout. The potential kill of the sub-adult ringed seal population could be 30% or greater, although its recovery is insured by isolation of its breeding stock.

The offshore leads in the transition zone, critical to the survival of overwintering ringed seals and breeding and feeding bearded seals, are consequently important areas for feeding polar bears and scavenging arctic foxes. Even though a major seal kill might not affect the eventual recovery of their populations, reduced numbers over several years will certainly affect the distribution and possibly the survival of the polar bears, and to a lesser degree, arctic foxes. The harm caused by oiling a bear's insulating fur or by the ingestion of oiled seal flesh and blubber is not known.

Spring (May and June): Wildlife in the Beaufort Sea exists in a harsh environment, not in the sense of low temperatures alone, but from a very abbreviated season of phytoplankton production. In this regard, May, June and July are the most important months of the entire year, when intense

spring illumination permits photosynthesis to proceed at a high rate. Animal life, particularly the zooplankton, are adapted to a short feast and thereafter a long famine. Within a few weeks, the invertebrates accumulate nutrient reserves for the production of eggs and to sustain them through the winter. Oil contamination of the surface and open water invertebrate communities could seriously impair their ability to capitalize successfully on the peak availability of food. The quantities of oil and its dispersion from a single blowout from either Canmar site are not likely to threaten long-term survival and recovery of the Beaufort Sea plankton communities. However, local depletion of the important spring production and of dependent invertebrates in the leads and ice of the transition zone could directly affect the migrant whales and seabirds which rely exclusively on these habitats for spring feeding. As in winter, the active leads off the mainland coast in Amundsen Gulf and west of Banks Island are also important spring habitats of polar bears and seals. Adult ringed and bearded seals breed from mid-March through mid-May. Although not gregarious animals, there is a seasonal aggregation of over 50,000 animals in the transition zone when they haul out to moult in late June, immediately prior to break up. The annual moult is known to be stressful for the seal; in spring the decrease in blubber can reduce an animal's weight by 23% to 40%. Oil from a previous seven months' accumulation in the transition zone and fresh pollution in the vicinity of the drill site could contaminate large numbers; potentially the majority, of bearded and ringed seal population. The added stress of contact with oil during the moult may be potentially lethal because of the low state of health of the animals.

It is not surprising that over 80% of polar bear sightings from late March to mid-May are concentrated on 9/10 to 10/10 ice cover near active leads, such as those in the vicinity of Baillie Islands. Ringed and bearded seals are concentrated here where the combinations of currents and winds form a persistent open pool, providing the animals easy access to the air. This type of habitat is mainly restricted to the transition zone where leads are widening in the springtime. A blowout at either of the two Canmar sites could contaminate, to varying degrees, up to one-third of this critical habitat during the winter of 1976-77. Avoidance of contaminated leads by moulting seals is not assured, hence if seal kills occurred they would affect dependent polar bear populations, some of which are international. Some fraction of the arctic fox and ringed seal populations of the Beaufort Sea are probably also international.

Annual spring migrations into the southeastern Beaufort Sea by whales and birds occur in May and June, when the impact of an oil well blowout would be greatest. Five thousand beluga whales and several hundreds of bowhead whales push through the leads and cracks of the transition zone in late April through to June. They feed on the concentrations of arctic cod and macro-invertebrates which are attracted to the leads by increased light and food. Beluga time their arrival for calving in Shallow and Kugmallit Bays and rely on the early spring food supply to prepare them for their month-long fast in estuarine waters. The modes of oil interaction with whales are unknown; possibly a local depletion of the white whales' food in the network of leads along the mainland coast (by about 25,000 m³ of oil) could alter the health of pregnant cows and subsequently the success of the year's calving. The presence of an oil slick contaminating the leads could complicate the whales' freedom to maneuver and delay their

arrival in the calving grounds. The loss of an entire year's calves, either from short-term human disturbances, or by natural causes would be of moderate significance to the population. To the Inuit who depend on the white whales' presence in Kugmallit and Shallow Bays for income and the recreation of the annual hunt, any displacement from traditional calving grounds would be unfortunate. It is clear however that oil from a blowout at either Canmar site is likely to greet large numbers of whales moving in leads; for example, 1,500 whales were observed in a polynya 25 km north of Toker Point (or about 35 km south of Canmar Site #1) in July, 1974. The prevailing ice conditions of the transition zone blowout will dictate the degree to which migrating whales would be exposed to oil.

Migrating seabirds will die in large numbers if oil, almost regardless of its type, quantity and state of weathering is encountered in the transition zone. Several million seabirds, geese and shorebirds migrate eastward along the mainland coast during May and June. The leads along the edge of the landfast ice are particularly important; here the diving birds such as oldsquaws and eiders, comprising as much as 90% of the entire offshore bird migrants, can rest and then feed on the benthic and nektonic fishes and invertebrates found in shallow continental shelf waters. Often the birds search at high elevations for patches of open water, including surface melt-ponds, when leads are scarce. Open water attracts most birds which have been observed to change their intended direction of flight to alight. Oil contaminated leads, open water and melt-ponds appear to attract diving birds if the oil is in sufficient quantities to calm the water surface. Since very small quantities of oil, often a few drops, can destroy the birds' thermal protection and waterproofing, the kill of seabirds could be very great. The ecological significance of the resulting kill, possibly 15% or more of the entire seabird population, would not be disastrous over the long term. This assumes that no population depletions occurred during the earlier migration along the Alaska and Yukon coasts, that there would be little additional mortality of nesting, feeding, staging and moulting birds, and that there would be only localized, short-lived pollution of the barrier beaches, river estuaries and coastal bays.

These are poor assumptions. The hypothetical blowout as viewed on May 5 could contaminate the leads and ice of the transition zone with an estimated 25,000 m³ of oil, spread as far west as the Alaska mainland. The American coastal barrier beaches and lagoons are extremely crucial resting, and feeding stops for migrating birds. Large numbers of eiders, oldsquaws, loons and gulls would have further chances of encountering polluted melt ponds on the ice surface, and along portions of the mainland coast such as Richards Island, Tuktoyaktuk Peninsula and the Yukon coast which will be polluted with oil, especially during the open water season of 1977.

In 1964 a 10% natural kill of migrating birds was reported along the Yukon coast. An estimated 100,000 eiders and other diving birds starved when the leads of the transition zone closed and refroze. Such a high natural mortality may not be common, however bird populations appear to recover quickly provided the lead habitats are available in subsequent years. If a large reduction in birds were to occur during the 1977 spring migration, the population could probably recover, if staging, feeding and breeding habitats are protected. The transition zone would be oil free in following

years assuming that a relief well successfully quenches the blowout in 1977. If there is a heavy ice year, such as in 1974, and a drill ship is not able to return to the blowout site, the wildlife mortality would be several times greater.

Summer (July to September): During the summer, the hypothetical blowout of 1976 could contaminate 400 km of mainland coast with the partially weathered remnants of 3,800 m³ of oil. The barrier beaches, sandpits, lagoons and bays of Richards Island, Tuktoyaktuk Peninsula, and, to a lesser degree, parts of the Yukon coast would be most directly affected. Colonial nesting birds such as terns and gulls as well as some shorebirds could be affected by oil fouling nesting sites. Many other bird species could be oiled during marine feeding forays in the nesting phase. Later, from mid-July to late August, many birds seek protection in coastal waters during the moult period. A general movement of birds occurs from freshwater lakes, where they nested and raised young, to coastal bays. This movement is likely connected with the moulting of flight feathers; as a result tens of thousands of flightless oldsquaws, scoters, scaups, mergansers and other species are concentrated in lagoons and other sheltered areas behind barrier beaches, especially along Tuktoyaktuk Peninsula.

Swans and geese which nest in river mouths, estuaries and salt marshes may suffer long-term damage to their nesting and feeding sites.

Inundations from storm surges and high river water levels occasionally flood nests and drown young. Oil carried inshore in concert with a storm surge would not only eliminate the annual production of young but could also pollute nesting sites in successive years. Chronic damage to vital nesting areas would significantly delay the recovery of bird populations following offshore kills.

Fall staging is another critical time for shorebirds, geese, brant, oldsquaws, scoters and scaups. These birds concentrate in traditional coastal habitats, particularly along the Yukon coast from Shallow Bay to the Blow River. Their staging areas are usually coastal marshes which are frequently water-covered each summer and offer nutritious sedges and grasses for birds prior to their migration southward. Snow geese, for example, gain up to one quarter of their body weight during staging, in preparation for long distance flights over unproductive taiga. Brant are even more dependent on the coastal littoral zone for their diet of aquatic plants. Oil which contaminates shoreline and lagoon vegetation could be redeposited in bottom sediments, thus affecting long-term plant productivity and benthic invertebrate foods. Oil could even be directly ingested by grazing swans and geese in search of roots and bulblets.

During the peak of the summer insect season, large herds of caribou and reindeer retreat to the Beaufort Sea Coast, including Richards Island and Tuktoyaktuk Peninsula. The onshore winds of the arctic coast reduce the severity of insect attacks, but more often the animals wade and swim in near-shore waters and bays seeking relief. It is probable that these large ungulates could encounter floating oil along the mainland coast and protected bays however, the result of such encounters is unknown.

Oil contamination of the nearshore waters in the outer Mackenzie Delta is probable during the whale calving season; strong northeast winds can drive the oil slick against the river flow and eventually inshore. An oil spill

in open water could presumably be avoided by these animals, as apparently occurred with migratory grey whales of Santa Barbara, California. Since whales apparently do not feed in the river plume waters, any depletion of summer fish stocks and benthic organisms by inshore oil pollution would likely go unnoticed by beluga. If the whales are forced to leave the contaminated part of the estuary, this interruption could reduce the survival rate of calves for that season. The subsequent recovery of the population may be only a matter of years. More harmful to white whales than oil pollution may be the future levels of summer noise and activity from machinery, ship and aircraft. If focussed in Shallow and Kugmallit Bays the whales could be forced into less suitable calving grounds.

In summer, the ringed and bearded seals are scattered along the mainland coast, offshore and near Banks Island. Oil slicks could easily be avoided by these animals. Although their food habits are varied, the coastal bays and lagoons east of Cape Bathurst are common feeding sites. If heavily polluted with oil, these highly productive waters containing benthos and fishes could be rendered useless to seals. Franklin Bay, for example, southeast of Baillie Islands, seems to be a nursery for large decapod crustaceans. These invertebrates are important in the bioeconomics of the Arctic as they are part of the food of beluga whales, seabirds and fishes as well as of seals. The decapods themselves feed on phytobenthos, detritus and small crustaceans, forming a close link to the primary part of the marine food chain.

THE VALUE OF ARCTIC MARINE WILDLIFE TO HUMANS

The Values: It is clear that the economic value, in absolute terms, of the harvest of fish and wildlife resources in the Beaufort Sea is very small indeed when compared with the expenditures involved in oil exploration or with the value of resources which it is hoped will be revealed by this exploration. On the other hand, it is also clear that to the people involved these resources have meaning and importance which greatly exceeds their economic value. The same can probably be said of the importance of the birds to people in southern Canada and the United States. The significance of the effects of an oil spill on these fish and wildlife populations therefore depends very strongly upon subjective value judgement, and is not easily quantified.

CONCLUSIONS

Extensive drilling operations in the Beaufort Sea will have substantial environmental and sociological impacts whether or not any major polluting incident occurs. The situation will have to be examined and dealt with by appropriate authorities as it evolves. However the drilling of two holes in the summer of 1976, which is the subject of immediate urgent concern, will not produce a sufficiently large increase of activity in the Beaufort Sea that a major impact will result unless an oil blowout should occur. Therefore attention is focussed on that possibility.

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Probability of a Blowout in the summer of 1976: It is very difficult to ascertain the probability of a blowout, since the number of offshore blowouts worldwide which produced substantial oil pollution has been too small to produce a satisfactory statistical base, and the particular conditions in the Beaufort Sea are unusual. Nevertheless, on the basis of information given by representatives of the industry and by DINA and DEMR the probability of an oil or oil and gas well blowout is judged to be in the range of 10^{-3} to 10^{-4} for each well drilled.

Environmental Threat from a Blowout at Proposed 1976 Drilling Sites: It is unlikely that oil discharged into the Beaufort Sea from a single oil well blowout running for several years would have any effect whatever on global or even local climate. Hence the main environmental threat is to the biota of the Beaufort Sea region. Both of the Canmar drilling sites are in the "transition zone", where winter ice is subject to movement of the order of kilometers per day, and where leads open, freeze over, and close throughout the winter in a manner which is not predictable in detail.

- Canmar Site #1 is positioned in the transition zone where a blowout is comparatively *most damaging* to plant and animal life because of the likelihood of winter and spring pollution of the active leads north of the mainland fast ice.
- Canmar's Site #2 is located in the transition zone where a blowout is *marginally less damaging* to overwintering wildlife since much of the winter oil discharge will be dispersed under the ice, at least until spring.

For comparison, a scenario was developed for a hypothetical Site #3 to reveal the effects of a blowout from a well drilled nearer shore where the ice is landfast in the winter. This scenario showed that a blowout is comparatively *least damaging* to overwintering marine mammals and spring migrants, assuming that burning at the blowout site is effective in the spring.

Drilling a Relief Well in 1977: The environmental threat ratings assume that the imaginary oil and gas blowout is controlled by drilling a relief well before October, 1977. This may not be possible since the 1977 ice year may be heavy and the subsequent open water season may be short. It is not possible usefully to predict the likelihood of light or heavy ice years. A blowout site can be continually ice-covered or ice-infested. This is more probable at Canmar's Site #2 than Site #1, and less likely at the landfast Site #3.

Considerations Affecting the Escape of Oil into the Environment: Available technology is severely limited in its capability of mitigating the threat to the environment arising from the loss of control of an offshore oil well, particularly in the Beaufort Sea transition zone. Unless a blowout were self-sealing, damage from released oil could only be prevented in one of three ways:

- a) The flow can be stopped by the drilling of a suitable relief well.
- b) The oil could be contained at or near the bottom.
- c) The oil could be contained or disposed of after it has reached the surface.

At present no technology exists for drilling a relief well in the Beaufort Sea transition zone except during the brief summer open water period. In some years no suitable open water period occurs.

There exists no technology for containing the oil near the bottom which is suitable for controlling escaping oil and gas in the Beaufort Sea transition zone.

Containment and disposal of oil at the surface is possible under certain limited circumstances. However existing technology is known to fail in modest sea and wind states such as occur for 55 to 60% of the time during the summer in the Beaufort Sea. According to scenarios developed in the Beaufort Sea Project, existing technology is unlikely to be successful in disposing of a large fraction of the oil which escapes during the winter period of moving ice.

The environmental prediction system which will be in place in the Beaufort Sea during 1976 and 1977 will not be sufficiently complete to permit prediction of the movement of escaped oil as accurate as is allowed by the state of the art. Thus the deployment of devices such as booms for the protection of especially vulnerable areas will be less efficient than is technologically possible.

Oil Spill Countermeasures in 1977: Canmar has endeavored to assemble equipment and develop methods to mitigate damage of oil pollution from a blowout. However, the harsh arctic conditions place severe constraints on the effectiveness of clean-up activities in 1976. New technologies adapted to arctic marine waters are in embryonic stages of development. As a consequence of an imaginary blowout on 5 October, 1976, and assuming a "standard blowout" (based on information received from the industry) in which the initial flow is 2500 barrels per day, reducing in a month to 1500 barrels a day and then continuing at that rate until the well is brought under control, it is concluded that:

- Most of the oil discharged from October, 1976 to early July, 1977 will escape containment and disposal at both Canmar sites. Approximately 25,000 m³ of oil will be mixed with the ice and water of the transition zone. Spring burning will have only very limited success. Spring burning of the oil might on the other hand be very effective for a blowout occurring in the landfast ice region.
- Fifty-five to sixty percent of the 21,000 m³ of oil discharged from July, 1977 to October, 1977, (the assumed month of well control), would be likely to escape containment and disposal at either Canmar site. Of the total amount blown by winds towards the coastlines, inshore oilspill countermeasures are unlikely to eliminate more than 5 %. On the other hand, where protection of specific bays and lagoons is sought, countermeasures would be effective for at least 45% of the summer.
- Oil spill countermeasures proposed for 1977 are not likely to decrease significantly the estimates of environmental impact of an oil and gas blowout occurring at either Canmar site.

Threats of a Blowout to the Arctic Marine Food Chain: An autumn oil well blowout at either Canmar site, but more so from Site #1, just north of the landfast ice zone, could pollute active leads and open water in the ice of the transition zone through the winter and spring. Assuming the blowout is controlled within one year, the oiling of these active leads, vital to the survival of marine mammals and birds will be shortlived. By the winter of 1977-78 the oil will have been dispersed northward into the Beaufort Sea Gyre and southward to the inshore waters and coastlines.

- It is predicted that primary production will be inhibited where oil collects in the ice of the transition zone so that a localized depletion of fish stocks, invertebrates and sub-ice algae will occur. This depletion would have significance if it occurred in the main E-W leads used for migration and in zones of active shearing used by resident seal populations. Seals, whales, some marine fishes and birds depend on the spring influx of food to recover from a winter's fast, a migration or an annual moult.
- The predicted mortality of overwintering ringed and bearded seals concentrated in the ice of the transition zone is not known; however, it is certain that a large fraction of the sub-adult and adolescent seal populations, perhaps 30% or more, in the southeastern Beaufort Sea will encounter oil.
- The predicted contamination of offshore leads for at least one spring season and the more chronic, long-lived pollution of the coastal bays and shorelines will have the greatest impact on the bird life of the southeastern Beaufort Sea.
- Coastal fishes comprise other wildlife populations sensitive to oil pollution. The recovery from an initial fish kill is predicted to be slow, perhaps a decade, a result of the persistent toxicity of oil in lagoon and embayment sediments.

It is evident that the effects of an oil blowout could be severe on some portions of the ecology and on some populations, particularly sea birds. However none of these effects is likely to be irreversible, although recovery might take as long as a decade in some cases. Except for birds, the economic values of marine wildlife resources threatened is of the order of tens of thousands of dollars per annum which is very small compared with the magnitude of the investment in the oil industry. Various estimates have been made of the economic values of migratory birds as a renewable continental resource -- in the order of millions of dollars per annum. Economic valuations of birds are exceedingly difficult to make on a sound basis, but the birds are visible throughout the continental flyways and are a substantial recreational resource having a high social and indirectly a high economic value. Even so, the importance of these consequences will have to be judged on largely sociological and environmental grounds, not economic ones.

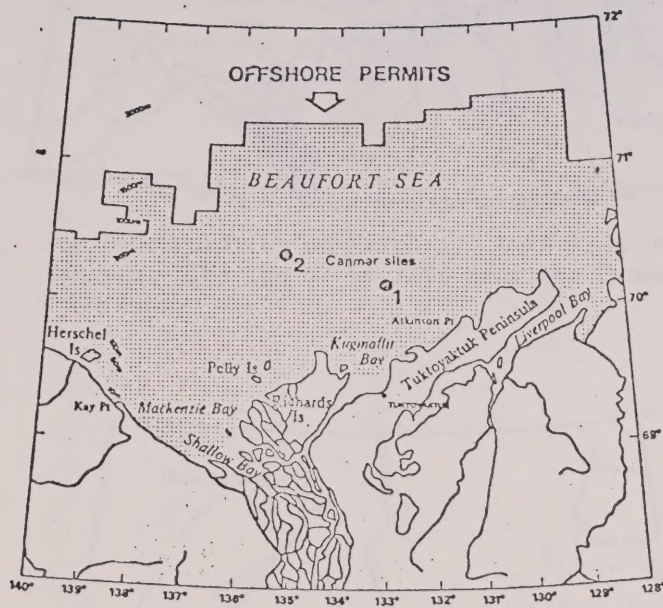


Figure 1. Offshore permits and Canmar's proposed exploratory, drilling sites.

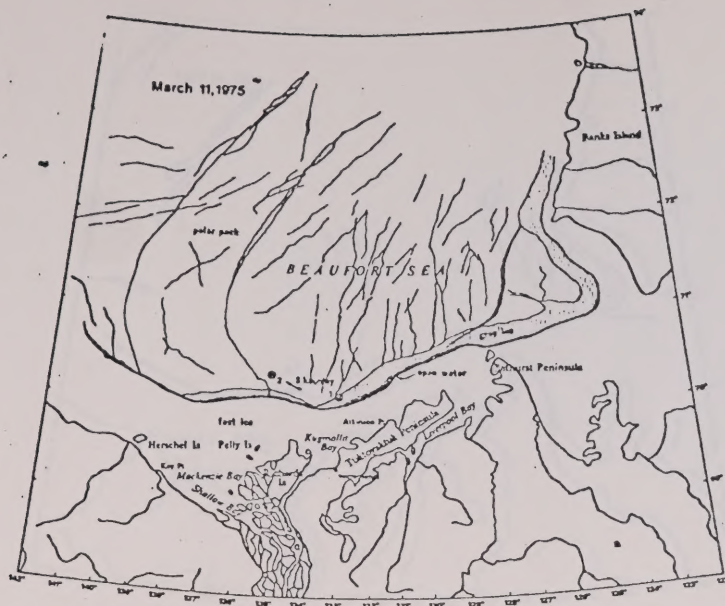


Figure 2. Ice configuration on March 11, 1975 from NOAA satellite imagery. The ice drift rate near the Canmar site was 8 km/day.

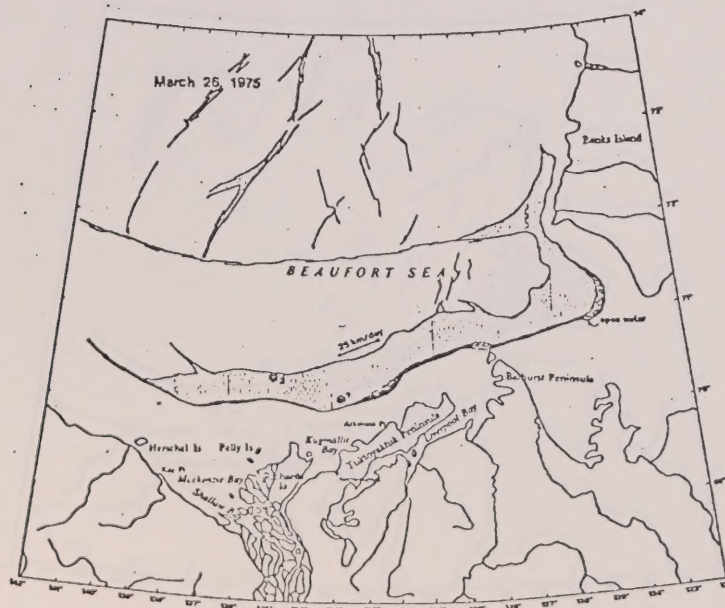


Figure 3. Ice configuration on March 26, 1975 from NOAA satellite imagery. Both Canmar sites are located within a wide E-W lead partially covered with new grey ice. The ice drift rate to the west was 25 km/day.

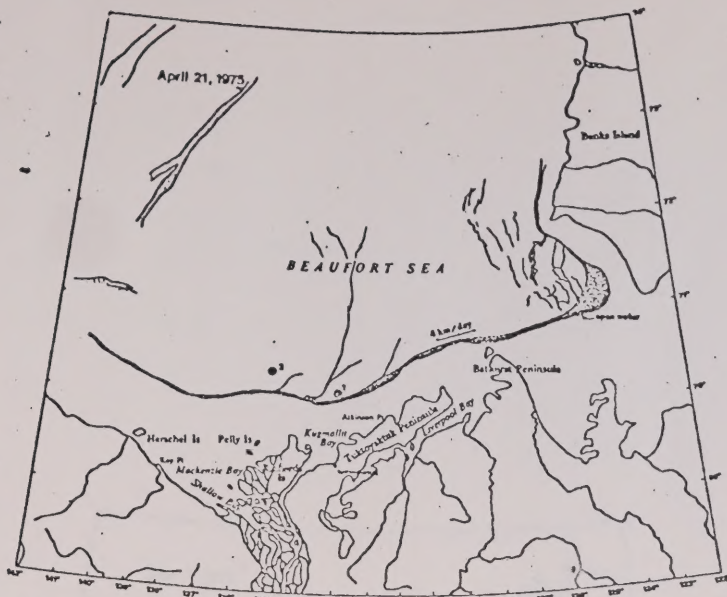


Figure 4. Ice configuration on April 21, 1975 from NOAA satellite imagery. The main E-W lead has narrowed and the ice drift rate has diminished to 4 km/day.

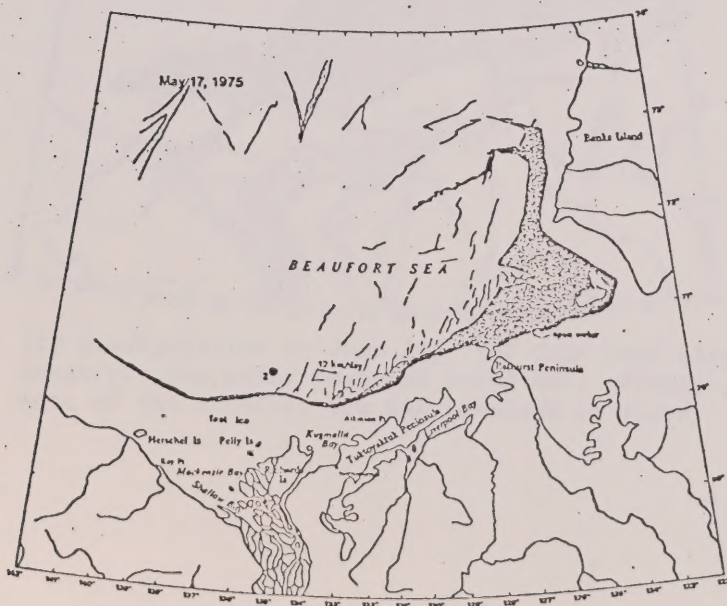


Figure 5. Ice configuration on May 17, 1975 from NOAA satellite imagery. A huge polynya has opened north of the Baillie Islands and the westward ice drift near the Canmar sites has increased to 12 km/day.

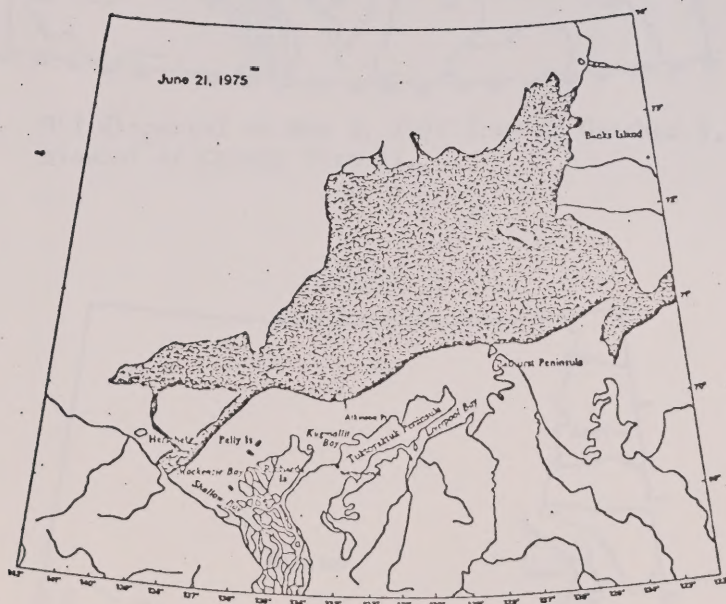


Figure 6. Ice configuration on June 21, 1975 from NOAA satellite imagery. The polar pack had moved well offshore, however most of the landfast ice had remained in place.

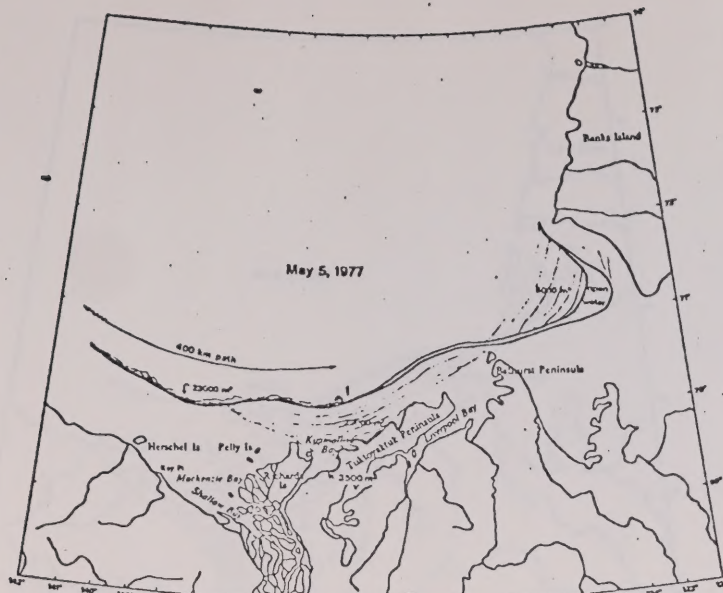


Figure 7. Oil dispersal on May 5, 1977 from an October 5, 1976 blowout at Canmar Site #1.

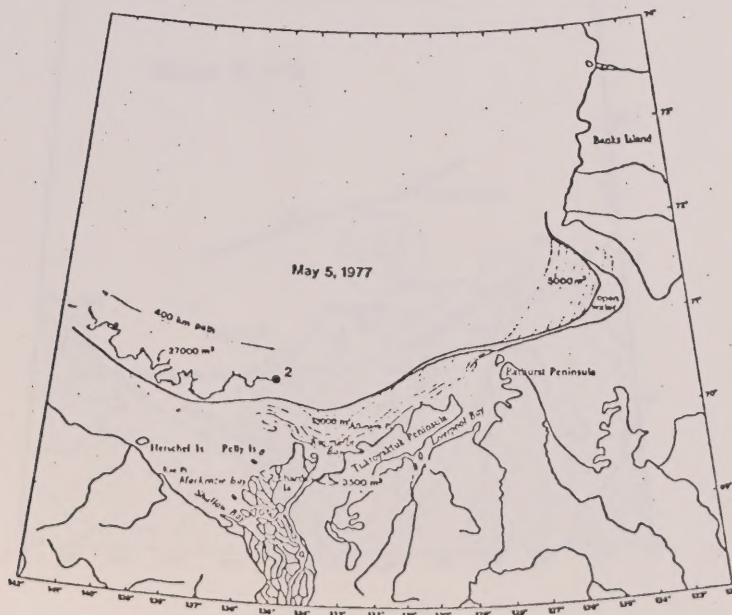


Figure 8. Oil dispersal on May 5, 1977 from an October 5, 1976 blowout at Site #2.

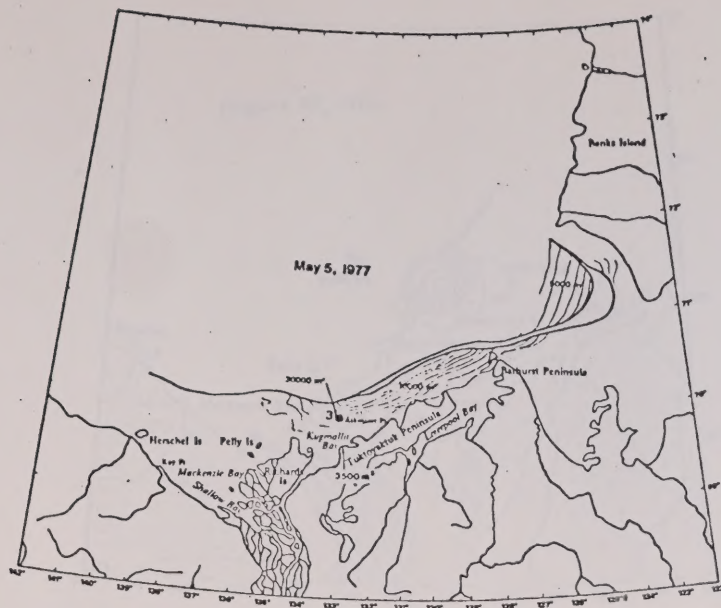


Figure 9. Oil dispersal on May 5, 1977 from an October 5, 1976 blowout at hypothetical Site #3 in the landfast ice zone.

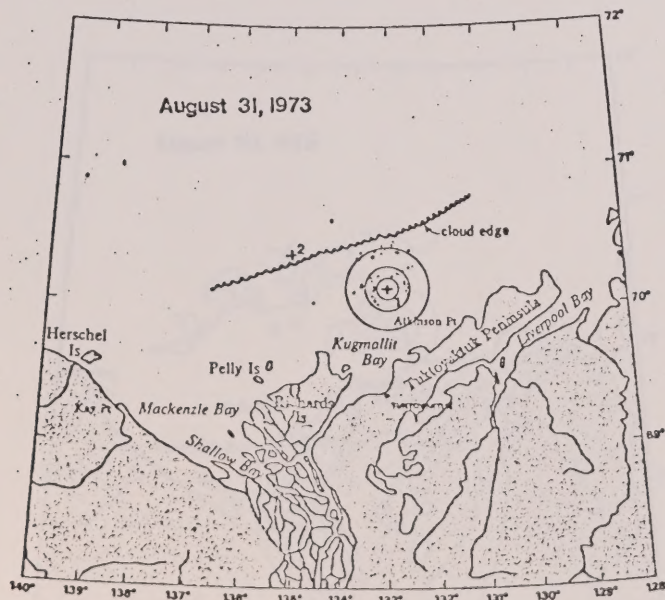


Figure 10. Ice floe intrusions on August 31, 1973 from satellite imagery. Small dots represent floes 1 km in diameter. Circles around Canmar Site #1 depict 24 hr, 12 hr and 4 hr alert zones assuming winds in the 10 to 20 kt range.

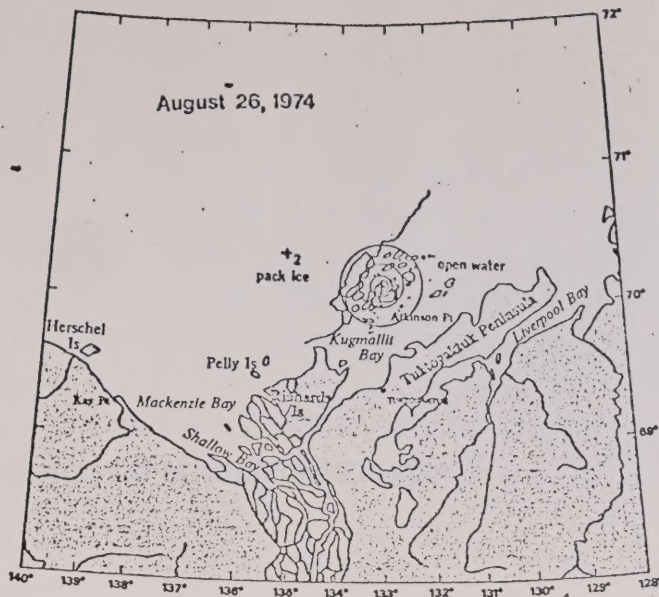


Figure 11. Ice floe intrusions on August 26, 1974 from satellite imagery. Circles around Canmar Site #1 depict 24 hr, 12 hr and 4 hr alert zones assuming winds in the 10 to 20 kt range.

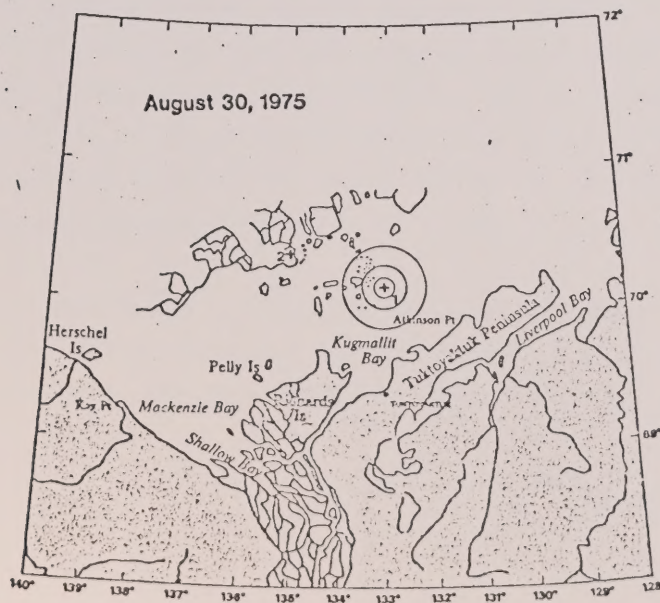


Figure 12. Ice floe intrusions on August 30, 1975 from satellite imagery. Circles around Canmar Site #1 depict 24 hr, 12 hr and 4 hr alert zones assuming winds in the 10 to 20 kt range.

TWO APPENDICES TO BE DISTRIBUTED LATER

- I. List of reports referred to or relied upon.
- II. Biographic information, A. R. Milne

ALLEN MILNE

Curriculum Vitae

Allen Richie Milne was born in Vancouver, B.C. on 27 October, 1921. In 1950 he received a B.Appl.Sc. degree in Engineering Physics at the University of Toronto and was then employed by National Research Council of Canada from 1950 to 1955 on microwave research and radar system design. During a year's break in this period he attended McGill University and received an MSc degree in Physics. The attractions of marine research then led to employment by the Defence Research Board of Canada at the Defence Research Establishment Pacific (then Pacific Naval Laboratory) in 1955, where he was employed on underwater acoustic research in Pacific Ocean waters until late 1958. He then turned his attention to unsolved problems in acoustic research in the Arctic in 1959, while at the same time following his interests in seismology and oceanography where they related to the acoustic environment. From 1959 to this date he has led twenty field parties in experimental programs in the Arctic. He is a Fellow of the Arctic Institute of North America and until November, 1973 was head of the Arctic Acoustic Group at the Defence Research Establishment Pacific in Victoria.

He is now head of the Arctic Marine Group with the Department of the Environment in Victoria and is also Project Manager for the Beaufort Sea Project.

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- # 1 - Distribution and Abundance of Seals in the Eastern Beaufort Sea
- # 2 - Distribution and Abundance of Polar Bears in the Beaufort Sea
- # 3 - Seabird Populations in the Coastal Beaufort Sea
- # 4 - Biology of the Bowhead and White Whale in the Beaufort Sea
- # 5 - The Effect of Contact and Ingestion of Crude Oil on Ringed Seals of the Beaufort Sea
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- #12b - Biological Productivity of the Southern Beaufort Sea: Zoobenthic Studies
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